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A drill for RQ-100

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ABSTRACT

An investigation of the optimum drill design for Bethlehem Steel Corporation's newly developed structural steel is reported here. The technique employed was the variation of breakthru torque and burr produced by changing the drill geometry.

The results show that chisel edge drills with wider included angles and lower relief angle performed better than spiral point drills from breakthru torque point of view. However, spiral point drills with lower included angles and medium relief angle performed better and caused less burr than the chisel edge drills with similar geometries.

A DRILL FOR RQ-100

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(date)

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Chairman of Department

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TABLE OF CONTENTS

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INTRODUCTION AND LITERATURE SURVEY

Though the pictorial evidence of the first drill occurs in a sculptured relief on the walls of mastaba of Tiye, at Saggara, dating about 2540 B.C., the origins of old spearpoint type drills are lost in the mists of antiquity. From the need in interchangeable arms manufacture, to drill many holes with speed and accuracy, made by the mechanics of New England, evolved the twist drill such as we know it today. One of the first firms to make these new drills was the Providence Tool Company of Rhode Island. However, it took the Civil War, to force the designers to perfect the earlier twist drill. Accurate twist drills were needed for forming holes in the percussion ripple of the new percussion lock rifle which was built in large quantities during the Civil War. Frederick Howe of above mentioned company took the problem of manufacturing twist drills to his good friend, Josef R. Brown, of Brown and Sharpe Company, who eliminated the problem by designing the universal milling machine to mill the spiral flutes of the twist drill. It was during 1862-1872 that the now familiar twist drills appeared in engineering work shops all over the world. Superficially the overall appearance of twist drill has changed very little over the past half century together with the fact that drilling of holes is one of the most widely used manufacturing processes. It is a conservative estimate that well over 100 million drills are used annually in United States alone. Because of this vast scale on which drilling operations are carried out, even a slight increase in the general level of drill performance would yield important practical and economic benefits to individual firms and the manufacturing industry as a whole. There have been improvements in drill tool materials and in drill accuracy. While these have yielded gains in tool life and potential hole accuracy, there have been relatively few changes in the basic twist drill design. The obvious variables such as helix angle of the flute, web thickness, surface finish and surface treatment have been thoroughly investigated. Other factors, like web concentricity and flute spacing that control the drill symmetry are carefully controlled in the production of twist drills. Presuming all above mentioned factors are under complete control, the most important variables that directly affect the performance are included point angle, relief angle and the point geometry. The basic knowledge of these factors and their effect on the drill performance would help the person involved to recommend the best drill for the job. A brief survey is undertaken with this in mind.

Drill symmetry is divided in two parts according to Mr. W. A. Haggerty. First being point grind symmetry, and the second part consists of web centrality and flute spacing. The effect of the first part on drill performance has also been investigated by D. F. Galloway and Carl Oxford, Jr. All the investigators come to the same basic conclusion. When the point is ground off centre, a difference in lip-height is obtained resulting in one cutting edge taking a bigger chip than the other creating an unbalance of forces between two. The drill point deflects away from the edge taking the larger force, tending to equalize the forces on two lips which results in the hole becoming oversize. It has been shown that average hole size directly varies with the relative lip height and the oversize for a given relative lip height is less with smaller included angles. Also drill life is sharply decreased for slight increases in relative lip height.

Because of the methods used in drill manufacture, web eccentricity and flute spacing go hand in hand. Hole oversize changes directly with the web eccentricity while drill life changes inversely with it, both relations being linear. It was also noted that when the web of the drill was more eccentric, the wear on one drill margin became more severe because of the large sidewise deflection of the drill. The author of the above paper noted that in some cases the wear was so great that the hole became smaller as the drilling progressed.

The spiral or helix angle of the drill largely governs the axial rake at the cutting lips and to a large extent chip clearing ability of the drill. An increase in helix angle decreases the torque and thrust required. The results are confirmed by Boston and Gilbert, Benedict and Hershey and by the U.S.A.F. machinability report. The selection of drill helix is usually based on the following factors; the depth of the hole and the material to be cut. The fast helix drills due to their better chip clearing capacity, are widely used in drilling of deep holes. However, this is not true when oil-hole drills are used in single spindle screw machine work. This type of work usually employs a low helix because the reduced helix angle tends to form shorter chips which are easily carried away by the coolant and because low helix construction in horizontal drilling also gives added strength and rigidity. The low helix angle is commonly associated with heavy duty drills required in machining of very hard materials and also some of the exotic materials now being used in the missile field. For general purpose H.S.S. drills the helix angle varies from 22° to 33° depending upon the drill diameter. High helix drills usually have lower torsional strength which is normally rectified by shortening of the flute and overall length to provide added rigidity if necessary.

Perhaps most effective among all the factors is the drill point. Configuration of the drill point consists of included point angle and the geometry of the point itself. Change in the included angle has an immediate effect on the performance of the drill. Drills with larger included angles between the range of 130° to 140° cut the harder materials more effectively.

On the other hand cast iron and some of the softer materials are drilled more efficiently with the included point angle in the range of 90° to 100°. Drills with the small included angles have longer cutting lips and they produce wide and relatively thin chip while the drills with large included angle produce narrower and thicker chips and hence are preferable in deep hole work because such narrower and thicker chips can be removed easily. The change in included angle will change the effective rake. The effect of helix angle of the drill is reduced when the included angle is small. The strength of the cutting lip is also increased, and hence sometimes smaller included angles will give better results while cutting harder materials. Long angle point drills, as 60° to 90° included angle is called, are commonly used in soft plastics and non-ferrous metals, while the flat angle point, as 130° to 140° range is called; used on tough and hard material. However, large included angle drills have a tendency "to walk" or skid on the surface of work when starting a hole and hence a guide bushing is suggested. The most common included angle is 118° and gives satisfactory results on variety of materials and is considered the conventional point angle. A modification in included angle is done while drilling medium and hard cast irons and other very abrasive materials. It is called double angle point. It has a conventional included angle in the central portion while a 90° included angle chamfer on the outer 1/3 of length of the cutting lips. The paths of chip flow from the two separate cutting lips cross and this interference causes the chips to break. Also, by the increasing of the cutting lip length and the cutting lip corner angle, rate of wear of the corner is reduced.

Another factor which completes the point configuration is the geometry of the point itself. It is basically three different forms, one being the chisel point and the other two are the spiral point and the crank shaft or split point, respectively. There are other variations of the split point geometry which go hand in hand with web thinning at the point. The latter two being the improvements in drill design and they eliminate the basic deficiencies of the chisel point. As the chisel edge length increases, total drill thrust rapidly increases and hence where the thrust, which may contribute to machine column deflection, is the main consideration, split point geometry is invariably used. Spiral point geometry will give the thrust values between conventional chisel point and split point. Chisel point gives the higher thrust values because cutting action at the chisel edge is mainly an extrusion process while the spiral point gives lower thrust values for the same work material because of effective cutting action and adequate space for chip flow in the region close to the axis of the spiral point drill which has a virtually continuous cutting edge from axis to periphery. Since the spiral point drill terminates at the axis in a sharp point, it therefore centers itself on the axis of the drill at the instant of engagement with the work. Other variations in point geometry are created only for the specific applications and hence are not reviewed here.

The last factor which affects the drill performance is nominal relief angle. However, its effect is not clearly isolated. Torque is practically independent of relief angles and the thrust values being highest for lowest relief angles and gradually decreasing as we increase the relief and becoming practically independent beyond the value of 10°, however larger values being effective while drilling cast iron. The relief on the drill must not only be sufficient to prevent metallic contact on the clearance face that may result from elastic recovery of tool and work but it also must include a component required to prevent the clearance face of the tool from being fed into the freshly cut surface.

To obtain the maximum benefits from the optimum designed tool, cutting conditions should be carefully chosen in light of existing equipment. The use of a pilot hole will cut the thrust in half but will have no influence over torque. Drill speed affects neither thrust nor torque. Both torque and thrust directly depend upon feed and hence wear. While the number of holes which may be drilled before resharpening will usually decrease with feed, the number of holes drilled per hour will increase with feed and hence, an optimum feed corresponding to minimum cost per hole should be used. But a dominating factor usually is the equipment capacity and condition. These dictate the speed and feed corresponding to the drill diameter. By controlling simple factors like drill overhang in chuck, absense of dust or burr in m/c, spindle rigid fixtures, chatter, vibrations, runout in the holes can be avoided and satisfactory results obtained.

THE EXPERIMENT

INTRODUCTION AND DISCUSSION

The drill performance can be and generally is evaluated on the basis of many different factors; drill life measured in terms of number of holes being most common. However, equally important are torque and thrust encountered, hole size variation, surface finish and temperature rise. There are various criterion by which all these factors are evaluated. Some authors have based their drill life on the following interesting observations. A change in color of drill, indicated by the dark blue end of the drill occupying the depth of hole drilled, a change in sound as can be detected by an experienced qualified and objective operator and a complete failure as indicated either by a scream, or radical chatter marks at the bottom of the hole. Thrust and torque have been shown to hold specific relationships with drill size and feed, having different constants pertaining to different work-tool material relationships. Sudden change in thrust and torque is still the best indicator of impending drill failure. Mean oversize variation in the mean hole size can be the best indicator where drill performance is being evaluated for close tolerance production drilling. The purpose of this project was to try to determine the optimum drill geometry for the steel developed by the Bethlehem Steel Corporation. It is basically a high strength structural steel with some variations adapted for particular applications. The properties and characteristics of the material are covered under work material and hence are not discussed at this time. The experiment was set up in close resemblance to shop conditions. The material is roller quenched and hence was used in as is condition so as to take the effect of scale into account. It was learned that material is drilled in stacked condition and hence thru holes were drilled.

SELECTION OF VARIABLES

a. Work Material - RQ 100 is the latest structural steel developed by the Bethlehem Steel Corporation. It has a greater strength/weight ratio than any other structural steel in the same field. RQ stands for roller quenched, 100 being the indicator of its yield strength. Other variations of this alloy being RQ-100A and RQC-100. These vary in chemical composition and are used where abrasion and corrosion properties are of more importance. RQ-100 is a quenched and tempered alloy steel plate with an exceptional combination of strength, toughness and wear resistance. It is ideal, as claimed by Bethlehem Steel Corporation, for pressure vessels and construction applications such as buildings, bridges, earth moving equipment, truck frames and other applications where high strength, toughness and abrasion resistance are prerequisites. This grade of steel is produced in plate thicknesses from 3/16 inch to 6 inches inclusive. It is water quenched from approximately 1,650°F and tempered at 1,100°F or higher and is utmost in uniformity of mechanical properties. RQ-100 steel plates can be machined with conventional equipment using either high speed steel or carbide testing. However, because of relatively high hardness of the RQ-100 steel as compared to carbon structural steel, the producers suggest that cutting speeds should be about 30% less than that used for carbon steel to obtain reasonable tool-life. RQ-100 meets the mechanical properties requirements of ASTM specifications A-514 and A-517. Its chemical composition and engineering properties are as follows.

CHEMICAL COMPOSITION

C	.12 - .21
Mn	.45 - .70
P	.035 max.
S	.040 max.
Si	.20 - .35
Ni	1.20 -1.50
Cr	.85 -1.20
Mo	.45 - .60
B	.001-.005

Mechanical properties applicable to a 2 1/2 inch thickness are given below.

Yield strength	100,000 psi
Tensile strength	115,000 psi
Elongations	18%

Brinelle hardness range - 235 - 293

Actual hardness graph for the material used in the experiment is given in Figure 1. The plates used were 1 3/4 inch thick and were torch cut in the sizes of 3 x 1 3/4 x 12 inches. To eliminate the tempering effect of torch cutting all holes were drilled at the distance of 3/4 inch, measured from the edge of the piece to the center of the hole.

TOOLS

The tests were conducted on an Edlund Model LHP2 drilling machine equipped with power feed. Drills used were high speed steel of Morse Drill Company make considering the horse power of the motor on the drilling m/c. It was decided to use the 1/2 inch diameter size. Of course, the results obtained for 1/2 inch size can be applied to bigger drills which will be used depending on the specifications of the drilling machine. The specifications of drills used were two flutes and a helix angle of 27° with taper shanks. To ensure as practical conditions as possible, the drills were used as they came from stock without modifications or individual microscopic examinations. When worn out, they were reground to original or various other geometries to be used again. To eliminate the effect of overhang, various geometries were randomly ground on the drills and random observations taken. The geometries of the drills were dictated by the choice of independent variables. These geometries were ground on the drills by machine and hence accuracies were ensured. Drill travel was maintained at 2 inches in order to ensure the drill hole is through

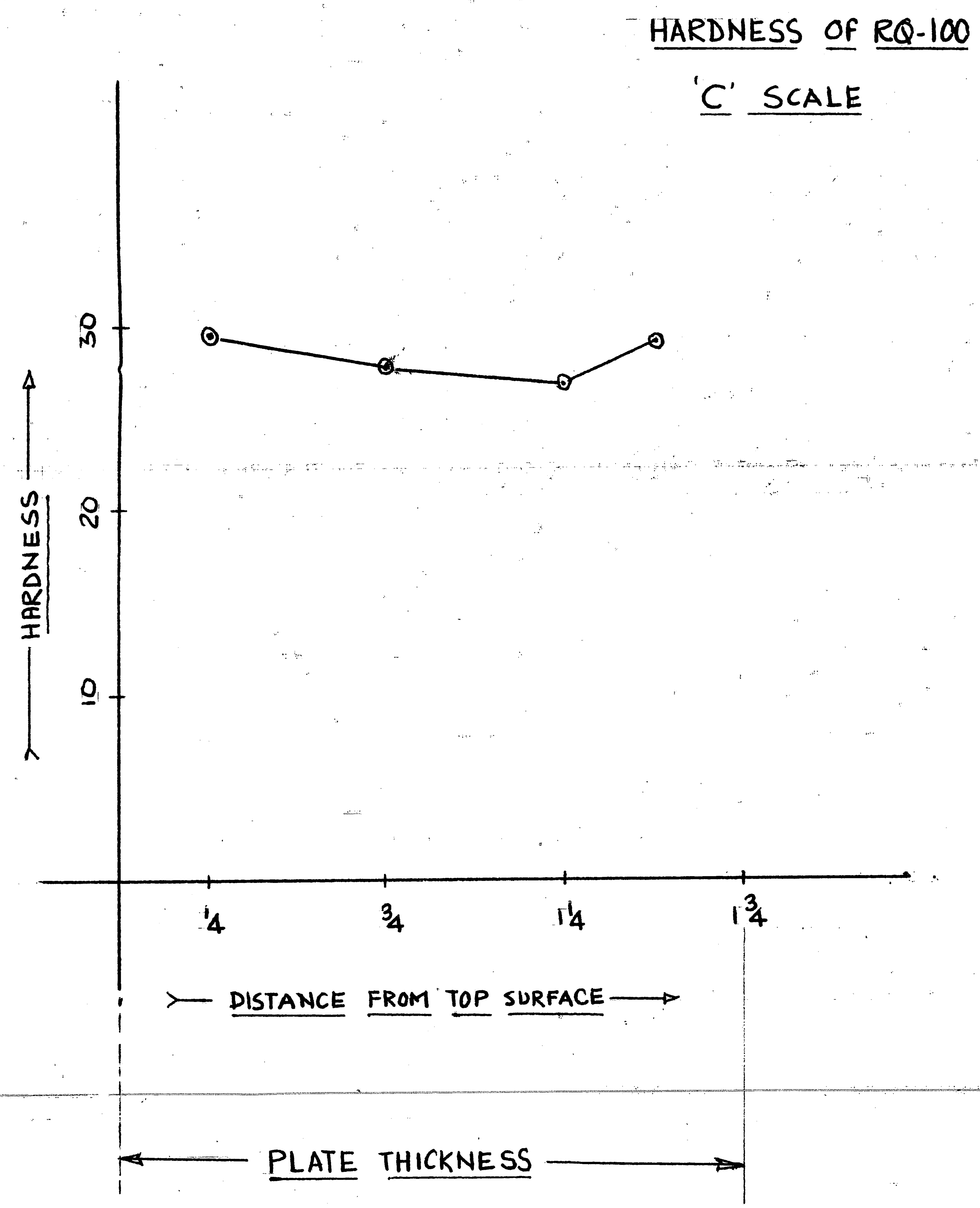

HARDNESS OF RQ-100
'C' SCALE
HARDNESS
30
20
10
1/4
3/4
1 1/4
1 3/4
DISTANCE FROM TOP SURFACE
PLATE THICKNESS

FIGURE 1

and the drill emerges from the material completely.

The three independent variables to complete the drill geometry were point angle (also called included angle), relief angle and the geometry of the point, i.e., either chisel edge point drill or spiral point drill. These three variables can be easily handled in any average size machine shop. The geometry which proves to be most satisfactory can be easily and readily ground in the shop itself and readily supplied to the production machines. Since the material was of higher hardness, it was decided to use the included angle in a higher range and the relief angle in a lower range. The different levels of these three independent variables that defined the drill geometry are:

INCLUDED ANGLE

118°, 130°, 140°

RELIEF ANGLE

4°, 6°, 8°

POINT GEOMETRY

Chisel edge point and spiral point.

DEPENDENT VARIABLES

It was learned that one of the problems while drilling RQ-100 was the burr produced by the drill when it emerged through the plate and as the holes in structural steel are used for putting bolts through, it was necessary to remove the burr to ensure that the bolt head or nut will fit snug with the surface. Thus, it was decided to measure the effect of drill geometry on the burr produced if there was any, and hence, one of the dependent variables measured was burr height. Another dependent variable measured for the evaluation of drill performance was the torque. However, since the material was stack drilled, breakthru torque was measured instead of average torque. The breakthru torque is defined as that increased value of average torque when the drill point emerges from the material while drilling through holes. Torque is important from a machine capacity point of view as well as critical torque point of view. Since it is directly proportional to the cubic power of drill diameter, critical torque values drastically go down as the sizes of drill decreases. In addition to this fact, the torque increases 20% to 50% with dulling of the cutting edges. These factors together may produce the breakthru torque which might contribute to the drill failure by breakage. The lower breakthru torques will always indicate good drill performance and less load on the machine adding to the accuracy of the operation. Besides these two dependent variables, one overall observation was made regarding the chip size and coloration and any indication of noise or chatter. Visual inspection of the hole surface finish was made periodically between the chisel edge and the spiral point geometries.

CUTTING CONDITIONS

First of all it was decided to use a dry cutting condition because it will add to the severity under which the drill will be performing and the optimum geometry obtained under this condition will only be enhanced by the use of a coolant or lubricant and will further the tool life and drill performance. Though the speed does not influence torque or thrust, it does have a profound effect on drill life. The accelerated wear of the lips and chipping of the corners happen at high speeds. Proper selection of surface cutting speed is essential. On the other hand, feed greatly influences thrust and torque and has a direct effect on machine stability and hence must be chosen by making a compromise between economic cutting and equipment condition. Excessive feed will give rise to higher thrust load causing spindle deflection, making the drill seize in the hole and break due to buckling load. Considering the importance of cutting conditions, it was decided to run a small pilot experiment to decide the optimum cutting conditions. Observed variables were torque encountered, hole surface finish, and cutting action of the drill (a visual observation of the cutting action of drill whether there is any vibration or chatter of the drill), chip formation and coloration of chip. Cutting speed was varied in four levels and three different values of feed were used. Because of the hardness of work material, it was decided to use 140° included angle with 6° relief (medium in the range) and a chisel edge point.

Observations were taken for 10 holes which was just an arbitrary number and all conditions were observed over this range.

As can be seen from the table, torque is almost constant over the speed range but increases rather rapidly with the feed. At the lowest value of feed torque is minimum and the drill is performing quite satisfactorily. However, the machine is not being used to full capacity and there is a chip problem. There is a question of which chip is most efficient, a long slightly curled chip or series of short broken chips. Most drills actually produce long chips until they are some distance in the hole. It is observed that during this period the drill is most free cutting and the coolant or cutting fluid has the best access. However, long unbroken chips obtained at the lower feed do get entangled with the drill and present quite a hazard to operator safety where jigs and protections are not used and hence totally undesirable. With increased feed chips tend to break in short lengths, but at higher rates of feed, excessive heating and laboring occurred indicating strain on the equipment making higher rates of feed undesirable. At the feed value of .004/rev. the drill produced long straw color chips and after a depth of that, short bluish color chips until it broke through. This indicated modest heating as the drilling progressed, heating being moderate over the range of 10 holes. However, when the feed increased to .006 inch/rev., this heating is accelerated giving blue short chips. Rapid heating of the drill is undesirable and hence it was decided to use the lighter feed and keep heating down as much as pos-

DETERMINATION OF OPTIMUM CONDITION

DRILL SPECS: 140° Included Angle, 6° Relief, Chisel Edge Point, 1/2 In. Dia. H.S.S.

FEED./REV.

	.004"	.006"	.010"
50	40# Long Stringy Chip. No Color, No Heating, No Labor. Good Hole No. 10.	75# Broken Chip. Bluish Color. No Labor, Good Hole. No. of Holes - 10.	110# Broken Bluechip. Heating and Light Laboring. Pair Hole No. - 10.
60	40 lb inc. Long Unbroken Chip. No Color. Good Hole. No. Labor. No. of Holes Drilled - 10.	60# Broken Chip. Bluish Color. Fair Hole, Toolmarks, No Labor. No. of Holes Drilled - 10.	130# Broken Chip. Blue Color. Heavy Heating. Laboring. Torque Increase. No. 3.
65	40# Stringy Chip. Straw Color. No Labor. Good Hole. No. of Holes - 10.	65# Medium Broken Chip. Blue Color, Light Labor, Good Hole, No. of Holes - 10.	130# Short Broken Blue Chip. Heavy Heating, Laboring. Fairhole. No. Holes - 10.
70	40# Broken Long Chip. Bluish Color. Good Hole. Welding of Chip at Cutting Edge. High Heating. No. of Holes - 10.	70# Broken Chip. Blue Color Heating. Laboring Heavy. Fair Hole. No. - 10.	Not taken because obvious overheating and Heavy Laboring.

sible. It was also observed as (the speed) increased, at higher feed rates, there was light chattering and laboring and hence the feed value was fixed at .004"/rev. With the change from lower speed to higher speed, there is not much change in torque but faster rates of penetration are achieved resulting in increased production. However, at higher speeds, increased heating and laboring was observed. At 70 sfpm at higher feed rates, excessive heating and laboring was observed and at a lower feed the chip was very long and quite unmanageable. It was observed that at a combination of 65 stpm and .004 feed, the drill performed very satisfactorily over the entire range of holes, torque was lowest and hole surface finish was good. Thus cutting conditions were established at 65 sfpm and .004"/rev feed with dry cutting.

EQUIPMENT AND INSTRUMENTS

1. Edlund vertical drilling machine
2. One component dynamometer
3. Sanborn recorder
4. Tachometer
5. Surface plate
6. Dial gauge mounted on the block
7. Spiropoint grinder

DESIGN OF EXPERIMENT

A simple factorial experiment was set up to study the effects of the three factors involved. The three different included angles along with three different relief angles were used for each point geometry. The factor A, i.e., point geometry had 2 levels namely chisel edge point and spiral point. The factor B (included angle) had three levels, 118°, 130° and 140° and the factor C (relief angle) had three levels also 4°, 6°, and 8°. Hence the experiment set up was a 2 x 3 x 3 factorial experiment. There were 18 different sets of experimental conditions and the experiment was replicated twice giving 36 trials in all. There were a total of ten observations within each cell giving in all 360 observations. The number of observations was an arbitrary number. It was felt that observed values of break through torque and burr height over the range of ten holes should give a reliable picture of the effects of the independent variables. The mathematical model for 2 x 3 x 3 factorial experiment will be as follows.

$$y_{ijke} = \mu + A_i + B_j + C_k + AB_{ij} + BC_{jk} + AC_{ik} + e_{ijke}$$

where y is the observed value and μ is the true mean and A, B, C stand for the above mentioned independent variables. Only first degree interactions are considered.

The actual sequence of 36 runs in the experiment was determined by randomization wherever feasible. Certain restrictions imposed by the experimental set up made complete randomization impractical. For example, spiral point grinding had to be done in the Homer Research Laboratories of the Bethlehem Steel Corporation and had to be done in batches, and thus complete randomization between spiral point and chisel edge was impractical. Subject to the above limitation cuts were randomized. The purpose of this randomization is essential to reduce the probability of any systematic arrangements between measured variables and possible experimental input variables. This quality of randomness in the sequence of test runs is an essential condition for making valid inferences from the statistical analysis of the data.

EXPERIMENTAL PROCEDURE

The work material, which was in the form of plate, was held in the vise which was clamped on the one component dynamometer which was bolted on the machine table. A Sanborn recorder was hooked up to the dynamometer to record the torque encountered. The work material was suspended in the rise in order to drill thru holes. Automatic feed was used and travel was adjusted whenever the length of drill dictated. For every combination ten holes were drilled in succession and everytime a drill finished one hole it was cleaned by a brush and any welding of the chip to the cutting lip or point was removed lest it should add to the increase of torque. The drills were used in as is condition and when one set of observations was finished it was ground to a different geometry and used again. Before any drilling, the work material was "prepared" by filing all edges so that the plate could rest flat on the surface plate in order to take the burr height readings. All holes were drilled at 1/2" from the edges in order to eliminate the

SCHEMATIC SETUP

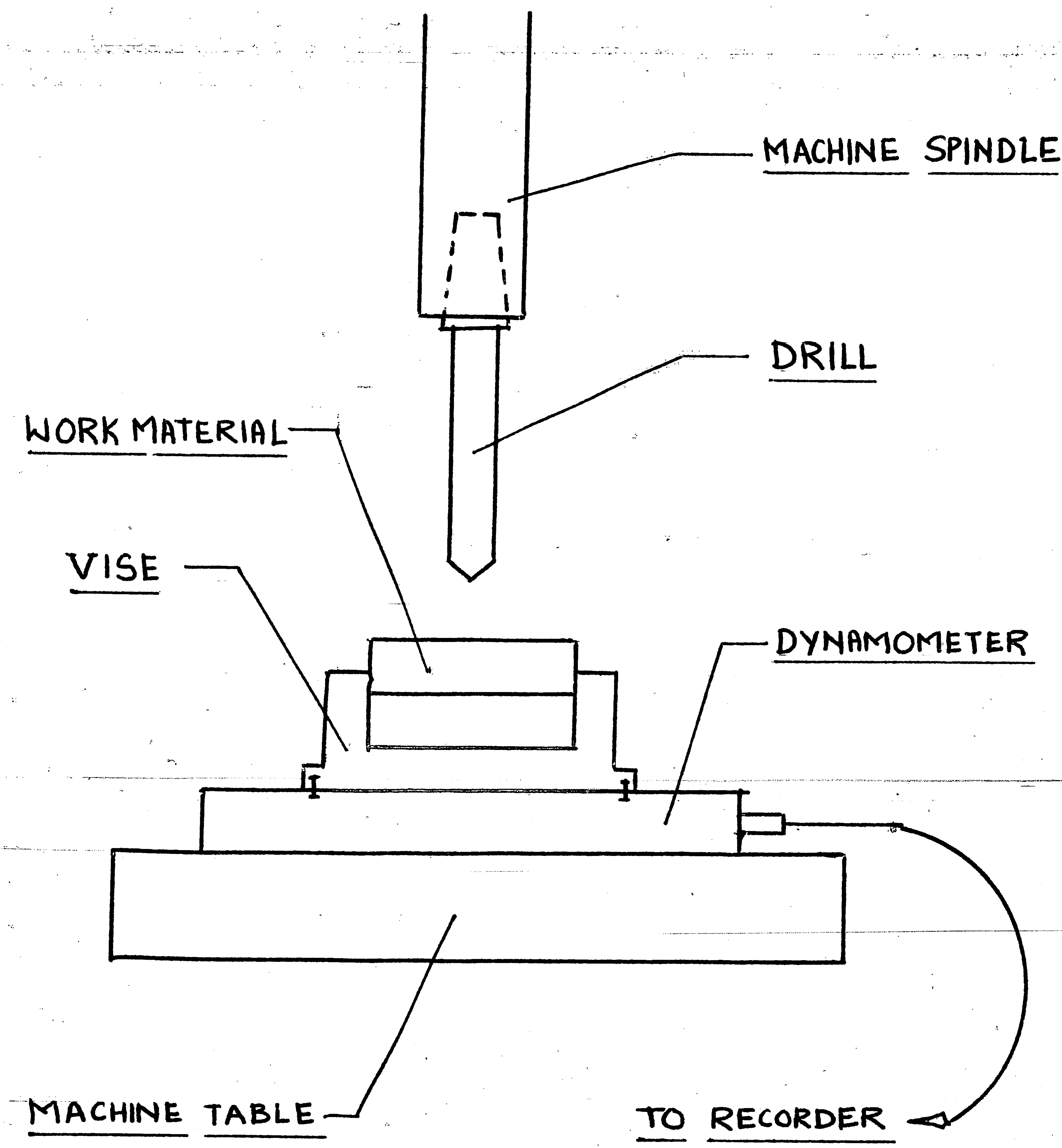


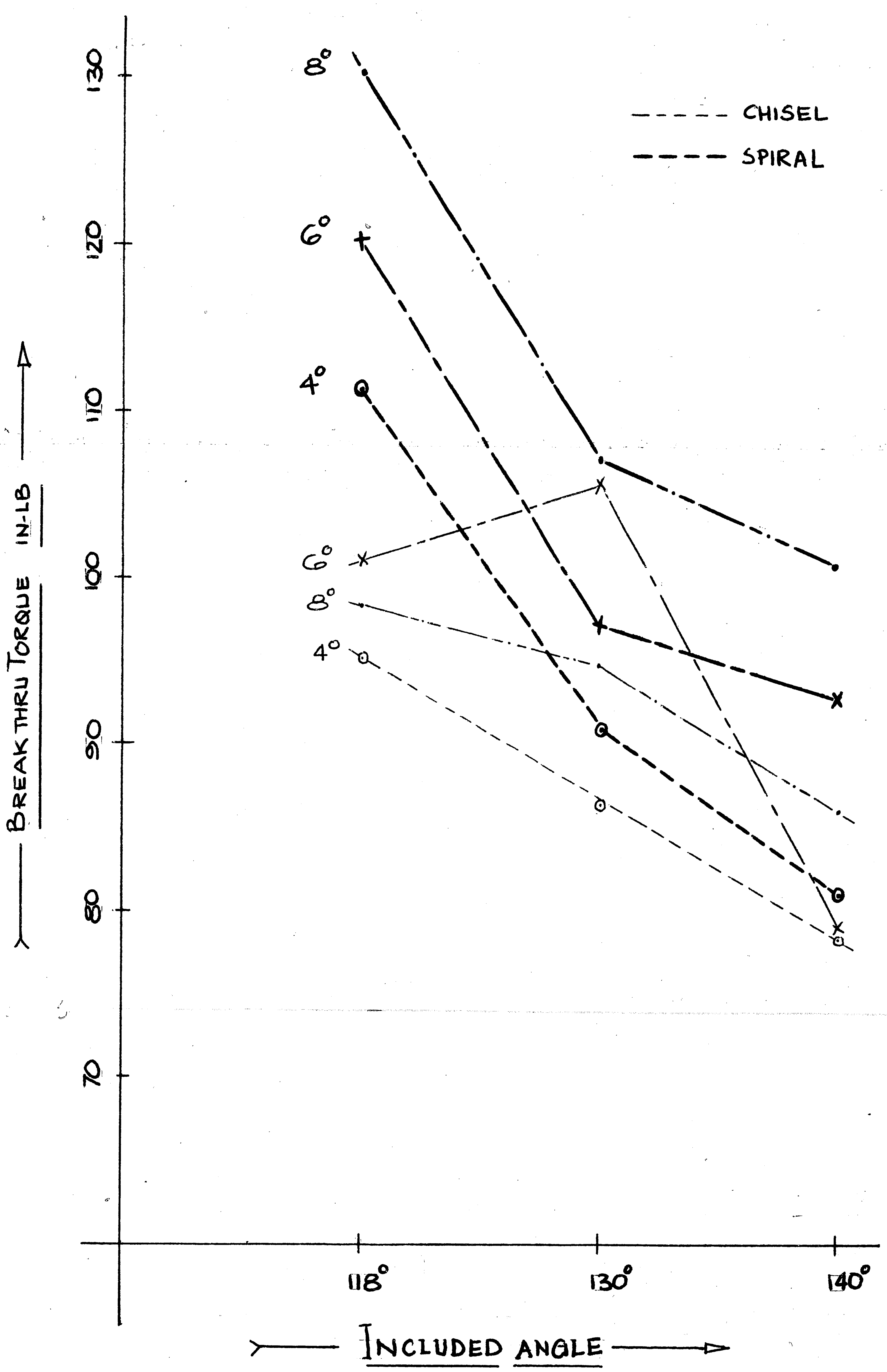
FIGURE 2

effect of change in microstructure caused by the possible annealing when the material was torch-cut into plates. As the material was assumed to be homogeneous, the variations in torque readings (instantaneous variations) were ignored. When the 10 holes were completed, the plate was kept on the surface plate, the underside thru which the drill emerges is facing up. All loose burrs were removed by brushing the surface with a wire brush. The purpose was to eliminate any burr caused by the scaly surface of the work material. The height of burr was measured by a dial indicator gauge. The dial indicator gauge was set to zero at the uncut surface of the plate and then the point of the gauge was moved along the periphery of the hole. Only the maximum reading was taken as the burr height. The procedure was repeated a couple of times and only the consistently observed value was taken down as the burr height. The torque value was taken from the plots obtained from the recorder. Also observed but not recorded were chip size and coloration and any chatter or smoothness of the drill performance.

RESULTS AND ANALYSIS

The results of the experiment are presented graphically in Figures 3 and 4. In these figures the mean values of breakthru torque and burr height are plotted against the included point angles. The raw data which make up these average values are presented in Appendix 1.

The analysis of the data was performed with the objective of finding which of the factors have a significant effect on the breakthru torque and the burr height. An analysis of variance was used to test the statistical significance of the differences in means shown in Figure 3. The results of these analyses are presented in Table 1. It is seen that for breakthru torque, changes in point geometry, included angle and relief angle independently are significant at 99.5% level of significance. The analysis of variance also points out significant interaction effects between point geometry and included point angle and also between point geometry and relief angle. The interpretation of this interaction effect is that the effect attributable to one factor, point geometry, depends upon the level of the other factor say included angle or relief angle. The physical as well as practical deduction can be that for the work material under experimentation, there exists a combination of point geometry, included angle and relief angle which would reduce the breakthru torque appreciably. However, the analysis of variance looks at all the data to determine which factors are important, but it does not tell



CHISEL
SPIRAL
8°
6°
4°
6°
8°
4°
130
120
110
100
90
80
70
BREAK THRU TORQUE IN-LB
118°
130°
140°
INCLUDED ANGLE

FIGURE 3

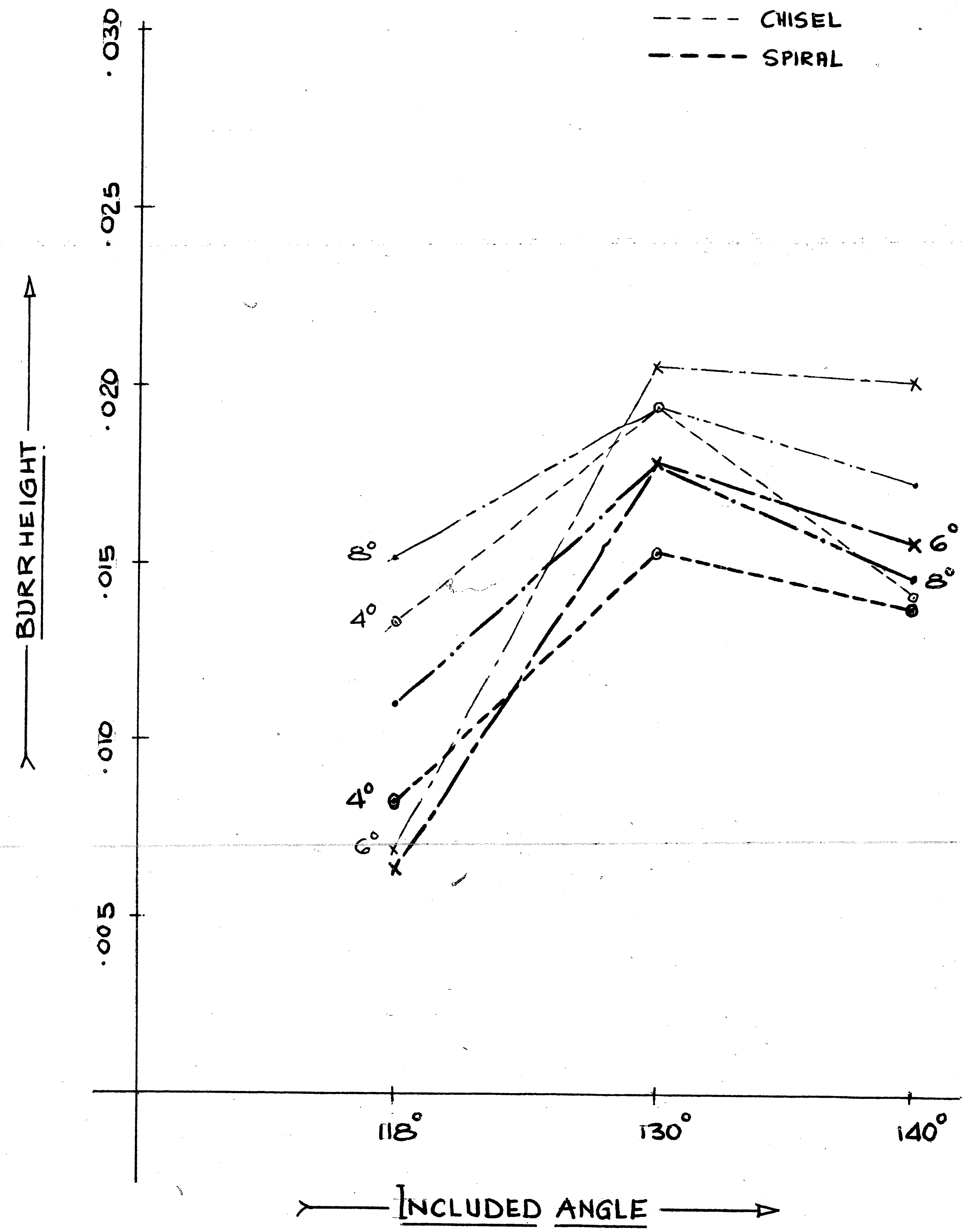

CHISEL
SPIRAL
BURR HEIGHT
·030
·025
·020
·015
·010
·005
8°
4°
4°
6°
6°
8°
118°
130°
140°
INCLUDED ANGLE

FIGURE 4

differences between the levels of factors involved. The student "t" test was used to determine whether the means of different levels of a given factor do really differ or do they come from the same population. It was assumed that the two populations had the same but an unknown variance. When the mean values of breakthru torque compared for two different point geometries namely chisel and spiral; the means differed for all included angles and for 6° and 8° relief angles, the level of significance being 99%. This is further confirmed from the analysis of variance data which shows a significant interaction between point geometry and relief angle indicating effectiveness of point geometry depending upon the values of relief angle, for the material observed. Similarly, means for all different included angles differed at the 99% significant level except for the 6° relief angle. There was a difference between 4° and 8° reliefs at the 99% level of significance. This does confirm that breakthru torque does depend upon the different levels of all three independent variables involved. Upon examination of the graphical representation of mean values for the torque, it is seen that the torque decreases as we increase the included point angle. It may be explained in the following manner. As the included angle decreases, chip thickness decreases, thereby increasing the specific cutting force and hence giving rise to the torque encountered. Also the direction of chip flow can influence the cutting forces. It is thought that if the cutting lip is either concave or convex, an additional compression or tensile force is set up within the chip in addition to a force outward between the chip and the wall of the hole. These forces increase the friction between chip and cutting lip, increase the force required to separate the chip from the work and impede the flow of chip thus increasing power requirement. It is also seen that torque requirement for the spiral point drills are higher than that of chisel edge drills. This is how it may be happening. Because of the nature of spiral point, the spiral drill ends in a sharp point at its axis eliminating any extrusion action and thus reducing the thrust; however, it's one continuous cutting lip from the point on its axis to the point on its outer periphery. Hence a longer length is engaged in direct cutting than with the chisel edge drill, thereby increasing the resultant cutting force on the lip and thus increasing the torque requirement. It is seen that lower value of relief angle favors the lower value in torque which is also established by other experimenters who recommend lower values of relief angle while drilling tough material. Thus the statistical analysis confirms that all factors under investigation have effect on the breakthru torque and it is possible to choose the optimum combination. It is apparent from the table, that combination of chisel point geometry with a 140° included angle and 4° relief will yield the lowest value of breakthru torque and should be used where torque is the main concern and the standard drill grinder is available. However, upon another look at the table, it is seen that spiral point geometry with same included angle and relief angles also gives the torque values in the same vicinity. Even though the spiral point is giving slightly higher values for torque while drilling RQ-100, it is quite favorable from the standpoint of surface finish of the hole, straightness of the hole, roundness of the hole and "smoothness" of the operation. Of course, availability of the spiropoint grinder is the deciding factor.

Analysis of variance for the burr height data indicates that the effects due to point geometry and included angle are significant at the 99.5% level. Relief angle effect is less significant. However, interaction effect between the included angle and the relief angle is significant at the 99.0% level and leads to the assumption that the effect due to the included angle depends upon the value of the relief angle. However, the "t" test done to determine whether means of included angles differ, or means of point geometries differ or means of relief angles are different, is quite inconclusive. However, for included angles, the means do differ for 118° and 130° and between 118° and 140° for spiral point geometry. More observations will be required to establish the significance level of the difference. Visual examination of the graphical representation of the mean values of burr height against the included angles for 118° the burr height is substantially low when compared with the one obtained for 130° or 140° included angle. It is apparent when we consider the following explanation. It has been established that the thrust increases as the included angle is increased. Thus lower values of thrust being given for smaller included angles. At the breakthru, there is the low value of thrust for smaller included angles and the penetration of the drill is gradual being more pointed and hence at the periphery of the hole, the last of the metal is being sheared off by the cutting edges. On the other hand, for wider included angles, the drill being flatter, the breakthru is more instantaneous and accompanied with higher thrust values and hence the metal at the periphery is pushed outwards instead of being cut. Thus higher thrust being responsible for possible plastic flow and hence the 118° included angle gives lower burr height. It is also seen that spiral point drills give the lower values for burr height as compared with chisel point drills having the other factors similar. Spiral point drills are well known for their smooth performance in cutting and absence of any extrusion action. They reduce the thrust by 20% to 40% thus giving low thrust values and hence the spiral point drill will give minimum burr height. A look at the table gives the optimum drill geometry as a spiral point geometry with a 118° included angle and a 6° relief angle. A chisel edge drill with the same included angle and relief angle is seen to give slightly higher values. Thus the choice ultimately depends upon the shop facilities available.

CONCLUSIONS

1. The independent variables (point geometry, included point angle and relief angle) proved to have significant effect on breakthru torque while other dependent variable (burr height) was affected by point geometry and included angle.

2. The spiral point drills were seen to cause the least amount of burr while the chisel edge drills produced the least amount of breakthru torque.

3. The spiral point drills were performing better from the point of view of heating, chatter and surface finish of the hole produced. From the color of the chips produced, considerable heating was involved in dry cutting and hence it is felt that a coolant instead of a lubricant should be used while drilling RQ-100.

FUTURE STUDY

1. In this experiment the optimum geometry of the drill was obtained with minimum emphasis of the feed and speed. It will be very desirable to carry out the experiment to determine the drill life, in terms of number of holes with speed and feed.

2. It was observed that heat was generated in considerable amount while drilling this material and hence effect of coolant on drill life and surface finish of the holes drilled, should be investigated.

3. Further experiment should be carried out to determine the variation of thrust with tool geometry and possible effect of thrust on the burr height in thru-hole drilling.

STATISTICAL ANALYSIS

TABLES

TABLE NO. 1

MEAN OBSERVATIONS OF TORQUE AND
BURRHEIGHT FOR VARIOUS DRILL GEOMETRIES

H.S.S. Drill. 65 SFPM.

RQ -100 Material. .004 FEED.

	Chisel Point			Spiral Point		
	118°	130°	140°	118°	130°	140°
4°	95.25	86.50	78.35	111.45	91.00	81.00
	13.45	19.50	14.10	8.25	15.60	13.95
6°	101.05	105.85	78.90	120.30	97.30	92.90
	6.90	20.60	20.15	6.50	17.85	15.55
8°	98.40	94.85	86.05	130.25	106.95	100.80
	15.25	19.40	17.50	11.20	17.80	14.65

UPPER VALUE IN A CELL REPRESENTS
BREAKTHRU TORQUE.

LOWER VALUE INDICATES BURRHEIGHT
IN THOUSANDS OF AN INCH.

ANALYSIS OF VARIANCE

BREAKTHRU TORQUE

<u>F Test</u>

Source of Variation	F Ratio	(F) Table	Level of Significance
1 Point Geometry	55.00	$F_{1},180,.005 = 7.879$	99.5%
2 Included Angle	69.80	$F_{2},180,.005 = 5.298$	99.5%
3 Relief Angle	20.80	$F_{2},180,.005 = 5.298$	99.5%
4 No. of Observations	0.433	$F_{9},180,.1 = 1.6315$	Less than 90%
12 Interaction bet. Pt. geo. and the Angle	12.85	$F_{2},180,.005 = 5.298$	99.5%
13 Pt. geo. and Relief angle	5.80	$F_{2},180,.005 = 5.298$	99.5%

BREAKTHRU TORQUE

(t) TEST: COMPARISON OF MEANS BETWEEN CHISEL POINT GEOMETRY AND SPIRAL POINT GEOMETRY

	Significance Level
4	95%
6	99%
8	99%
4	80%
6	80%
8	98%
4	50%
6	99%
8	99%

BREAKTHRU TORQUE

Comparison of means between Included angles. (t) test.

Relief	Chisel 118-130	Chisel 130-140	Chisel 118-140	Spiral 118-130	Spiral 130-140	Spiral 118-140
4	99%	90%	99%	99%	99%	99%
6	50%	99%	99%	99%	50%	99%
8	50%	95%	99%	99%	50%	99%

BREAKTHRU TORQUE

Comparison of means between Relief angles. (t) test.

	Chisel			Spiral		
	4-6	6-8	4-8	4-6	6-8	4-8
118	50%	50%	50%	50%	50%	99%
130	90%	50%	95%	50%	90%	99%
140	95%	95%	80%	99%	50%	99%

ANALYSIS OF VARIANCE

BURR HEIGHT

f test

Source of Variation	F Ratio	(F) From Table		Significance Level
1 Point Geometry	9.66	$F_{1},180,.005$	= 7.879	99.5%
2 Included angle	28.40	$F_{2},180,.005$	= 5.298	99.5%
3 Relief angle	1.462	$F_{2},180,.10$	= 2.308	Less than 90%
4 No. of Observations	.816	$F_{9},180,.10$	= 1.63	Less than 90%
2.3 Inc. angle and Relief angle	3.36	$F_{4},180,.001$	= 3.31	99%
2.4 Relief angle and No. of Observations	1.461	$F_{18},180,.10$	= 1.44	90%

BURR HEIGHT

Comparison of means between Included angles. (t) test.

Relief	Chisel 118-130	Chisel 130-140	Chisel 118-140	Spiral 118-130	Spiral 130-140	Spiral 118-140
4	80%	50%	Less than 50%	99%	Less than 50%	98%
6	99%	Less than 50%	99%	99%	Less than 50%	99%
8	50%	Less than 50%	Less than 50%	95%	50%	90%

BURR HEIGHT

Comparison of means between point geometries. (t) test.

	118	130	140
4	99%	50%	50%
6	50%	50%	90%
8	50%	50%	50%

BURR HEIGHT

Comparison of means between Relief angles. (t) test.

	Chisel			Spiral		
	4-6	6-8	4-8	4-6	6-8	4-8
118	95%	95%	50%	50%	95%	50%
130	less 50%	50%	50%	50%	50%	50%
140	95%	50%	50%	50%	50%	50%

RAW DATA

118 - Included Angle

BURR HEIGHT

	Chisel			Spiral		
	4	6	8	4	6	8
	.016	.003	.006	.003	.010	.016
	.013	.001	.000	.005	.003	.010
	.014	.002	.011	.003	.005	.010
	.022	.004	.018	.008	.006	.010
	.036	.015	.010	.006	.002	.008
	.016	.011	.012	.010	.004	.014
	.014	.002	.024	.014	.002	.012
	.015	.012	.024	.005	.001	.020
	.016	.000	.028	.007	.003	.015
	.018	.008	.018	.009	.002	.022
Average	18.0	5.8	15.1	7.00	3.8	13.7
	.011	.028	.000	.008	.008	.005
	.014	.012	.019	.018	.017	.008
	.005	.006	.011	.006	.000	.002
	.004	.004	.046	.020	.003	.004
	.005	.003	.007	.012	.005	.018
	.000	.006	.006	.003	.005	.009
	.004	.003	.005	.006	.011	.010
	.038	.000	.025	.006	.016	.004
	.005	.004	.010	.001	.013	.020
	.003	.014	.025	.015	.014	.007
Average	8.9	8.0	15.4	9.5	9.2	8.7

130° Included Angle

BURR HEIGHT

	Chisel 4	Chisel 6	Chisel 8	Spiral 4	Spiral 6	Spiral 8
	.022	.020	.013	.012	.023	.010
	.019	.011	.026	.013	.028	.015
	.018	.036	.024	.016	.028	.013
	.001	.010	.024	.017	.033	.013
	.001	.009	.022	.032	.016	.025
	.020	.014	.026	.028	.032	.028
	.008	.024	.028	.004	.014	.044
	.008	.022	.010	.006	.036	.012
	.004	.015	.003	.008	.030	.021
	.004	.014	.018	.006	.018	.001
Average	10.5	17.5	19.4	14.2	25.8	18.2
	.030	.014	.010	.020	.004	.010
	.044	.002	.018	.017	.005	.010
	.024	.021	.040	.022	.007	.023
	.016	.020	.011	.004	.004	.020
	.019	.026	.017	.020	.004	.015
	.022	.030	.008	.030	.024	.018
	.034	.037	.026	.014	.008	.014
	.034	.044	.026	.023	.015	.018
	.030	.021	.018	.020	.010	.028
	.032	.022	.020	.010	.018	.018
Average	28.5	23.7	19.4	17.0	9.9	17.4

140° Included Angle

BURR HEIGHT

	Chisel			Spiral		
	4	6	8	4	6	8
	.009	.013	.008	.015	.008	.011
	.005	.020	.018	.009	.020	.018
	.005	.024	.022	.012	.016	.017
	.010	.038	.030	.010	.018	.010
	.035	.042	.016	.015	.018	.019
	.015	.009	.012	.011	.017	.011
	.014	.020	.012	.018	.014	.016
	.004	.026	.013	.016	.020	.017
	.003	.022	.044	.023	.020	.022
	.006	.005	.014	.022	.022	.013
Average	10.6	21.9	18.9	15.1	17.3	15.4
	.020	.019	.004	.007	.010	.009
	.015	.019	.015	.010	.017	.017
	.014	.018	.011	.008	.010	.020
	.032	.022	.007	.010	.017	.010
	.013	.015	.013	.018	.015	.021
	.015	.019	.028	.007	.015	.017
	.016	.014	.022	.008	.013	.013
	.013	.025	.014	.018	.018	.013
	.022	.018	.015	.032	.008	.015
	.016	.015	.032	.010	.015	.010
Average	17.6	18.4	16.1	12.8	13.8	13.9

118° Included Angle

B.T.

	Chisel			Spiral		
	4	6	8	4	6	8
	77	75	105	112	100	120
	87	95	100	92	90	110
	90	97	110	110	95	125
	102	92	108	130	130	122
	90	92	97	110	120	175
	90	90	97	105	110	125
	90	85	97	115	100	130
	90	80	95	110	115	135
	95	85	105	115	115	140
	95	75	102	110	100	140
Average	90.6	86.6	101.6	110.9	107.5	132.2
	95	125	85	100	105	135
	101	115	110	106	155	120
	87	110	135	110	130	140
	100	110	90	120	160	110
	115	130	85	100	118	108
	105	115	100	110	118	130
	95	110	85	130	175	115
	100	120	85	120	115	145
	100	120	82	112	120	135
	101	100	95	112	135	145
Average	99.9	115.5	95.2	112.0	133.1	127.3

130° Included Angle

B.T.

	Chisel			Spiral		
	4	6	8	4	6	8
	87	120	90	85	92	115
	75	110	75	89	95	140
	85	112	70	85	85	128
	85	105	82	75	105	112
	82	87	86	90	105	115
	87	90	90	100	90	130
	90	85	72	100	105	120
	77	87	110	95	115	90
	82	80	100	110	100	115
	100	82	102	100	105	120
Average	85.0	95.8	87.7	92.0	99.7	118.5
	90	115	90	85	80	100
	87	130	95	100	85	92
	80	145	107	83	80	83
	81	160	100	100	115	95
	95	120	110	80	90	95
	80	130	103	90	95	92
	105	97	110	90	95	115
	95	90	100	85	87	97
	80	85	100	100	130	100
	87	87	105	87	92	85
Average	87.8	115.9	102.0	90.0	94.9	95.4

140° Included Angle

B.T.

	Chisel			Spiral		
	4	6	8	4	6	8
	77	85	65	65	87	87
	75	77	68	68	115	90
	65	65	82	76	120	120
	65	85	85	75	92	95
	60	95	85	75	105	80
	60	72	80	82	90	70
	65	75	82	75	83	100
	65	80	90	72	85	95
	65	80	110	70	105	75
	75	100	82	75	125	125
Average	67.2	81.4	82.9	73.3	100.7	93.7
	105	75	82	90	80	110
	90	80	95	95	72	110
	80	75	90	87	75	122
	100	75	95	83	80	95
	95	80	82	85	80	112
	110	82	88	82	92	110
	80	80	90	97	90	115
	80	70	92	100	90	115
	80	77	90	83	97	90
	75	70	88	85	95	100
Average	89.5	72.4	89.2	88.7	85.1	107.9

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